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A review on the Central America electrical energy scenario

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ABSTRACT

Since the mid 1990s, after the pacification of Central America, the region has experienced a sustained economic growth. Additionally, the Central American governments have been able to increase the population's access to electricity, e.g. the percentage of Central American population with access to electricity in 1995 and 2010 was 59% and 86%, respectively. The aforementioned reasons and the need to reduce electricity costs in order to remain competitive in a global economy have produced a transformation of the power scenario in Central America.

The present paper presents a review about the power generation scenario of Central America within the framework of the new Regional Interconnected Electric System. It also briefly analyzes the trends of the power generation profile with a special emphasis on the renewable energy sources. As it can be inferred from the analysis presented in this paper, the Central American power scenario will mainly be shaped by the participation of the private sector and the development of the recently created regional electricity market. Additionally, it is clear the willingness of all the Central American countries to move away from oil-fired power generation. The lack of up-front capital needed to develop large renewable energy projects (mainly hydropower) can favor the development of gas-fired and/or coal-fired power stations. Nevertheless, the regional electricity market may favor the viability of large power generation projects.

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1. Introduction

The need for investments to meet the increasing energy demand and, in some cases, the debt crisis, has led to a process of deregulation and privatization of the electricity market almost everywhere.

The electric energy scenario has also changed due to the evolution that non-traditional power generation technologies have had in recent years. For instance, wind and solar power generation have become more attractive not only because both technologies have experienced a steady decrease on their costs but also because they represent a highly scalable energy solution. Scalability is a highly desirable characteristic – especially in developing countries – because it allows to test a new technology at a relatively low cost. Consequently, it seems reasonable to envisage a future electricity market in which several low to mid distributed power generation units deliver energy to the utility grid.

Small countries can be especially affected by the transformation of the electric energy scenario. Take for instance the case of El Salvador, a Central American country of only 21 000 km^2, in which the privatization of its electricity market has led to a sudden rise in prices for the consumers and eventually forced the government intervention [1]. According to [1] the aforementioned situation was mainly due to the small size of the Salvadorian market which failed to attract enough private companies and to create a healthy competitive environment.

In this regard, integration of energy markets across boundaries seems to be not only a viable but also a necessary option for small developing countries. The rational behind the integration of energy markets is not only related to the potential financial savings that might be achievable but also to the need to cope with the intrinsic variability of the new renewable energy technology (e.g. solar and wind) that is gaining importance in the power grid, i.e., larger power grids can profit more efficiently the diversity and complementary properties of renewable energy sources.

Central America has been dealing with the integration of their local energy markets since the 1970s [2]. In 1996 the Central American presidents signed an Electricity Market Framework Treaty that, along with subsequent regulations, set the legal framework for energy transactions between the Central American countries. At that time, the existing regional electrical interconnection infrastructure was weak and unable to operate above 50 MW. Consequently, the main priority of the aforementioned agreement was to construct the required infrastructure for the efficient interconnections of the local power grids. The construction of the dedicated transmission line started in 2006 and has been finished in 2013. It is expected that the regional market will be activated with the finalization of a dedicated power grid infrastructure with much larger power capacity [3].

The Central American energy scenario has been previously analyzed and described in not many published international scientific papers. Most of the works have focused their attention on the relationship between energy consumption and economic development, such as the studies mentioned in [4]. In this regard, the latest study performed on this matter, i.e. [4], concludes "*that energy consumption in Central America plays an important role in the growth process both directly and indirectly as a complement to labor and capital*". Other studies deal mainly with the regional cooperation efforts both to create an integrated energy market and to lower CO_2 emissions [1,5]. For instance, the study performed by Hosier et al. in [5] concludes stating that the "*integration of the Central American region can result in considerable benefits in all aspects of the energy sector, particularly in the power subsector*". In [6], Flores et al. present a diagnosis of the Honduran energy economy. The authors also analyze policies and investment needed to improve the Honduran energy market. In the aforementioned work, the authors also highlight the unexploited potential of natural resources available in the Central American region for producing clean energy.

This document presents a review about the power generation scenario of Central America within the framework of the upcoming regional interconnected electric system. It also briefly analyzes the trends of the power generation profile. It should be pointed out that similar reviews of countries' energy scenarios have been presented in [7–10] for the cases of Indonesia, Iran, Malaysia, and Pakistan, respectively.

2. Central America: geography and demographics

Central America is the region of the Americas that lies between North America (Canada, United States and Mexico) and South America. Geographically speaking, seven countries constitute this isthmus, namely, Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama. All of them except for Belize share a common language, culture and infrastructure. For instance, the Pan-American Highway connects the six countries and represents the main trade route between them. Also, a recently completed Central American Electrical Interconnection System connects the power grids of the six countries, allowing also the trade of energy between them.

Moreover, since the mid 1990s there have been a consensus among Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama, to create common institutions and discussion groups to coordinate the actions of the countries in terms of power policy, energy investments and electrical tariffs. For instance, the Central American Electrification Council is a regional organization, created in 1979 and formed by the institutions in charge of planning the power expansion of the aforementioned countries, that have had a central role in the consolidation of the regional electricity market.

Belize has not actively become part of the regional institutions or the regional integration process in Central America. This might be due to cultural and language differences and the territorial disputes between Guatemala and Belize.[1] Additionally, in terms of regional integration Belize has been closer to the Caribbean islands; it has been a member of the Caribbean Community (CARICOM) almost since its creation (1974). In this regard, the situation of Belize with respect to Central America is similar to that of Guyana and Suriname, also members of CARICOM, with respect to South America. Moreover, the energy interaction between

[1] The territory of Belize has been claimed in whole or in part by Guatemala since 1940.

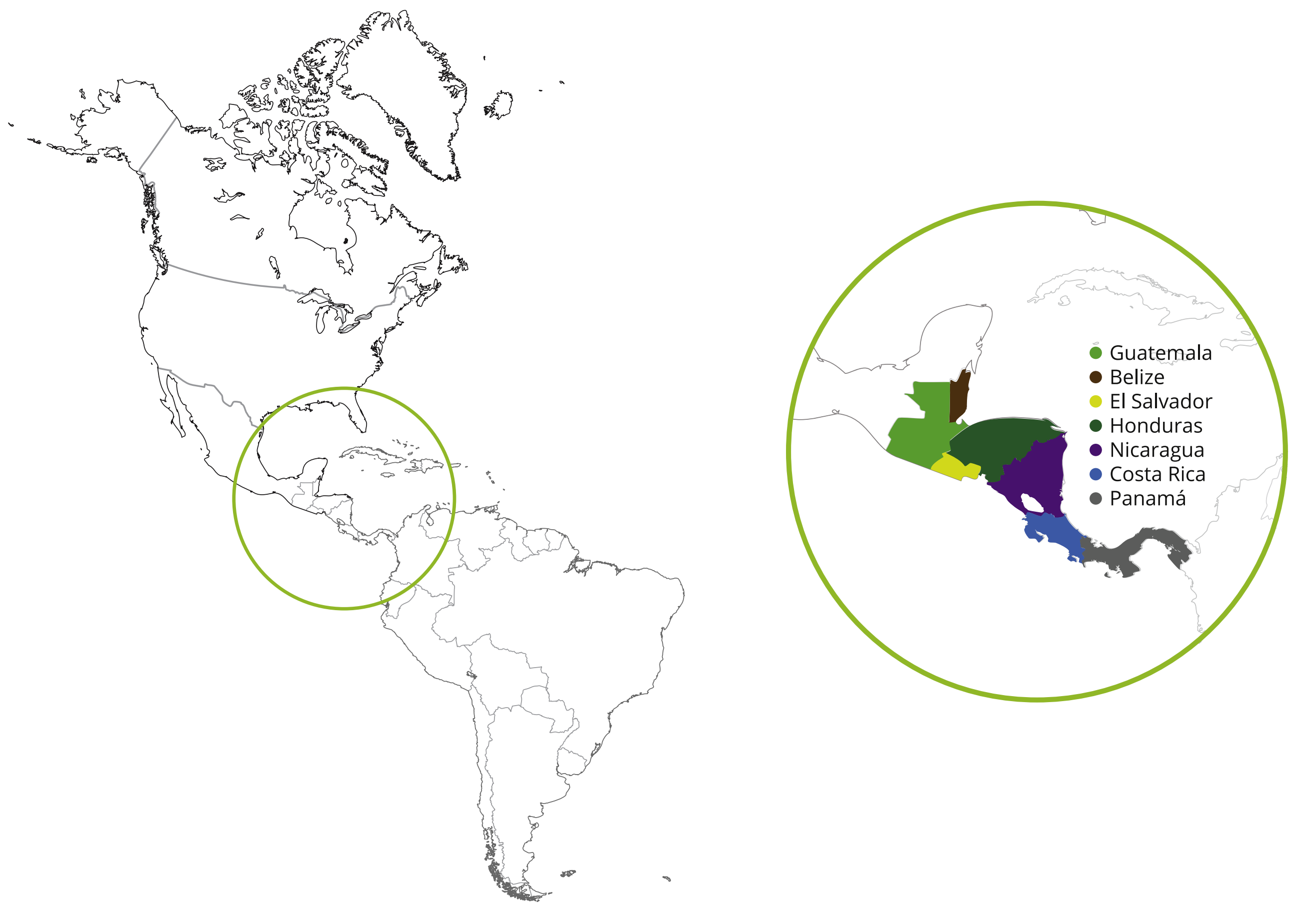


Fig. 1. Map of Central America.

Belize and the rest of Central American countries is almost null, Belize imports power from Mexico, from which it is electrically interconnected.

Due to the aforementioned reasons, in the present paper, the energy scenario of the region consisting of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama will be analyzed. The mentioned countries are referred in this document as Central America.

Central America lies between latitudes 7° and 18°N and longitudes 77° and 93°W. It has a total area of almost 500 000 km^2, a little bit bigger than California, and 1.65 times the size of Italy. The population of Central America is similar in number to that of California or Canada, that is, roughly 41.4 million inhabitants. It is bordered by Mexico in the North, Colombia in the South, the Caribbean sea in the East and the Pacific Ocean in the West (Fig. 1).

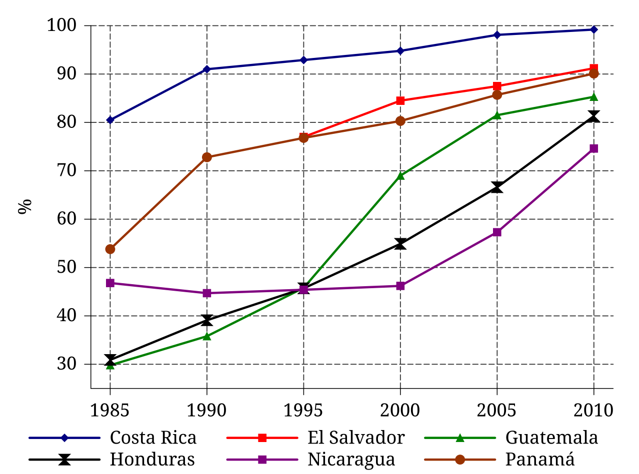


Fig. 2. Percentage of the total population with access to electricity in Central America from 1985 to 2010.
Source: Economic Commission for Latin America [14].

3. Central America electricity market: background and current situation

Central America has always produced “clean” electric energy. In 1985, electricity generated from hydropower and geothermal accounted for 82.7% of the total electricity generation [11]. Currently, the electricity generation is still mainly obtained from renewable resources. According to the Economic Commission for Latin America (ECLA) [12], 64.9% of the total electricity generated in 2012 used renewable energy resources.

Since 1985 the region has experienced significant demographic changes. From 1985 to 2011 the population increased 67% going from 25.7 million to 42.8 million [13]. Whereas the rural population slightly increased, the urban population doubled. Since the 1990s, and mainly due to the pacification of the region,[2] Central America has also improved their macroeconomic indicators, for instance, the 2011's gross domestic product per capita with respect to that of 1990 has at least tripled in each Central American country [13].

[2] From the late 1970s major internal violent conflicts and revolutions started in various countries in Central America. An effort from several Latin American nations was able to work a resolution that ended the region's wars in the early 1990s. Since then, the region has been able to avoid armed conflicts.

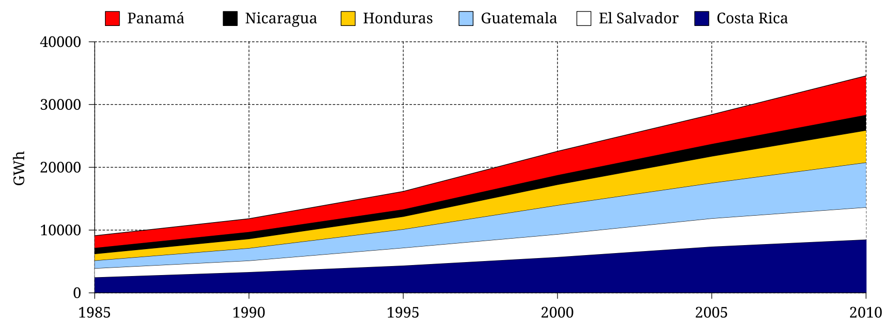


Fig. 3. Electric energy consumption from the power grid in Central America from 1985 to 2010.
Source: Economic Commission for Latin America [14].

In parallel, the Central American governments are putting a lot of effort into increasing the population's access to electricity. As reported by ECLA, in 2010 85.9% of the Central American population had access to electricity [14]. In Costa Rica, El Salvador and Panama more than 90% of the population has access to electricity. The evolution of the population access to electricity in the region can be seen in Fig. 2.

Evidently, larger urban population and better economic conditions come with larger energy consumption. Indeed, in 2010 the electricity consumption in Central America increased 280% with respect to the electricity consumption in 1985, as it can be verified in Fig. 3. The maximum electric power demand has also increased considerably in every Central American country (see Fig. 4).

In the early 1990s almost all the Central American countries decided to restructure and deregulate their electric markets not only because they wanted to be part of the competitive global economy, in which input cost reductions are essential, but also because, after the armed conflicts, weakened public institutions did not have enough money to invest in new power generation projects. In general, the objectives of the reforms in the electricity sector in the majority of the Central American countries have been to introduce competition to operations such as electricity generation and electricity retailing and to regulate only the natural monopoly components, transmission and distribution, of the electricity network. It was expected that the liberalization of the electricity sector would improve the efficiency of electricity utilities, ensure the security and sustainability of electricity supply and encourage investment and innovation.

3.1. *Local electricity markets*

During the 1990s almost all the Central American local markets have been restructured. Table 1 lists the Acts that define the current legal frameworks of the local Central American electricity markets along with the most important reforms introduced. Notice that the actual legal framework of the Central American countries permits the creation of a competitive wholesale market with the exception of Costa Rica. Following, the main characteristics of the local electricity markets are described based on the legal frameworks mentioned in Table 1 and on the technical reports of the Areca's Project of the Central American Bank for Economic Integration, i.e., [15–21].

3.1.1. *Costa Rica*

As mentioned previously, Costa Rica maintains a state-owned vertically integrated electric utility structure. The "*Instituto Costarricense de Electricidad*" (ICE) is the public institution that controls the transmission and most of the distribution and generation of the country. In 2010 ICE was responsible of producing 72.8% of the total

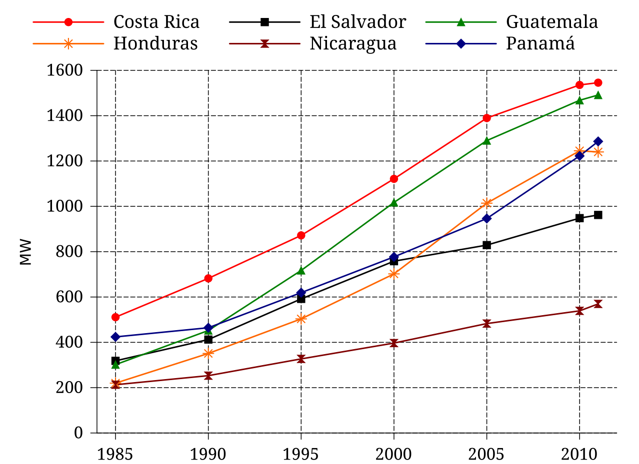


Fig. 4. Maximum electric energy power demand from the power grid in Central America from 1985 to 2010.
Source: Economic Commission for Latin America [14].

electricity generated and selling, along with its subsidiary CNFL, the 78.7% of all the electricity. The prices from generation, transmission and distribution are regulated by a public regulatory agency, ARESEP. By law[3] Independent Power Producers (IPPs) can contribute to at most 30% of the total electric energy of the interconnected national system. An IPP can sell energy to ICE, the unique wholesale electricity buyer in Costa Rica, using two different mechanisms:

1. Request for eligibility, in which an IPP presents a generation project proposal to ICE, so that ICE declares it eligible for power generation. In this case, the proposed IPP's central station should have a capacity of at most 20 MW and should use only renewable energy sources. At least 35% of the share capital of the IPP should be owned by Costa Rican. The sum of all the IPPs that sell energy under this scheme should not surpass the 15% of the total electric energy of the national interconnected system. The IPP's electric power selling price is defined by the public regulatory agency based on the current prices and a technical report elaborated by the IPP.
2. Build-operate-transfer (BOT): In this case ICE opens a public tender for the construction and operation of a specific type of power station. This power station can only be based on renewable energy sources and it should be limited to a maximum capacity of 50 MW. The price of the energy is negotiated within the bidding process but with a maximum value set by the public regulatory agency. The sum of the electric energy generated by all the power

[3] Act 7200 from 1990 and Act 7508 from 1995.

Table 1
Latest reforms of the local electricity markets in Central America.

Country	Legal framework	Major electricity market reform
Costa Rica	Act 7200 (1990) and Act 7508	Allows the participation of private power stations that use only renewable energy
El Salvador	Act 843 (1996)	Establishment of a wholesale market; allows private companies in all the electric energy activities; privatization of transmission and distribution; created spot market
Guatemala	Act 93–96 (1996)	Establishment of a wholesale market; allows private companies in all the electric energy activities; privatization distribution public companies
Honduras	Act 158–94 (1994)	Establishment of a wholesale market, allows private companies in generation and distribution
Nicaragua	Act 272 (1998)	Establishment of a wholesale market; allows private companies in generation and distribution
Panama	Act No. 6 of 1996	Establishment of a wholesale market; privatization of generation and distribution public companies

stations under this scheme cannot surpass the 15% of the total electric energy of the national interconnected system.

3.1.2. El Salvador

El Salvador is the only Central American country that has an electricity market that has retail level competition. Any private company is free to generate, transmit, and distribute electric energy. Moreover, independently of their consumption, each consumer has the right to choose its electricity provider and negotiate the conditions and price of supply.

A private company, named "*Unidad de Transacciones*" (UT) operates the electrical interconnected system and administrates the wholesale market. UT's shareholders are the largest agents of the wholesale market. The only public company that operates in the electricity market in El Salvador is "*Comision Ejecutiva del Rio Lempa*" (CEL) which owns the vast majority of the hydroelectric capacity.

Any company that wishes to participate in the wholesale electricity market in El Salvador requires a valid interconnection contract with a transmission or distribution company, then it should sign up a service contract agreement with the operator of the wholesale market. Power stations larger than 5 MW that make use of public goods to produce electric energy (e.g. hydropower or geothermal) have to participate in a competitive tendering process.

3.1.3. Guatemala

Guatemala has also deregulated the power generation activities. In 1998 the government has privatized the entire distribution network. During the electric market reforms, the government unbundled legally and administratively the electricity generation, transmission and distribution.

Guatemala has two types of electricity markets:

- a regulated market conformed by consumers with a power demand less than 100 kW and distribution companies, and
- a wholesale market which comprises generators with a capacity larger than 5 MW, distributors that serve a minimum of 15 000 users, companies that transport energy with a transmission capacity of at least 10 MW, the retailers and the consumers with a power demand larger than 100 kW.

IPPs require an authorization from the Guatemala's National Commission of Electrical Energy to access the electric energy infrastructure. If the proposed power central makes use of public goods (e.g. in the case of hydroelectric or geothermal station) it will also require an authorization from the Ministry of Energy and Mines (MEM). Power stations with a lower capacity than 5 MW do not require MEM's authorization and can make use of an abbreviated process for their interconnection with the electrical interconnected system (i.e., they only require an authorization from the distribution company to which they wish to sell energy). The Guatemalan utility company, "*Instituto Nacional de Electrificación*" (INDE), is obliged to buy all the energy produced by small hydropower stations with a power capacity ranging from 200 to 3000 kW. In this case, the IPP only needs to negotiate with INDE the power purchase agreement.

Electric energy self-producers (EESPs) which are also consumers can inject their surplus to the distribution system without selling. If at the end of the month the distributor registers a net energy injection it will provide an energy credit for the EESP. For this kind of operation no authorization is needed from a government agency.

3.1.4. Honduras

Honduras was the first Central American country to adopt reforms of its electricity sector. In 1994, according to the new legal framework, generation, transmission and distribution companies can be owned by public, private, or mixed ownership operating enterprise. Indeed, Honduras attempted to establish a competitive power market model, however, after failing to attract private companies to participate in the distribution activity, the public utility company, "*Empresa Nacional de Energía Eléctrica*" (ENEE), remained as a vertically integrated company, with participation in the generation, responsible for electricity purchases and the procurement of all the energy to meet demand. Thus, the market envisioned in the law was not implemented because the distribution networks were not unbundled and privatized [6,22].

In the current de facto energy situation an IPP wishing to inject energy to the Honduran power grid first needs to sign an operation contract that allows it to operate as an agent in the national sub-electrical sector. Then, it can sell energy to ENEE using two different mechanisms:

- requesting a Power Purchase Agreement (PPA) to sell energy to ENEE and
- participating in a public tender offer opened by ENEE.

The details of the PPA (e.g. pricing) are defined by ENEE and the National Energy Council, the entity that serves as the regulatory agency of the electricity sub-sector, however recommendations and suggestions from stakeholders and the developer of the project are usually also considered.

3.1.5. Nicaragua

In Nicaragua transmission and distribution of electrical energy are regulated by the state. Moreover, all transmission is handled by "*Empresa Nacional de Transmisión Eléctrica* (*ENATREL*)", which is also in charge of the interconnected system's energy dispatch. On the other hand, companies that are dedicated to the generation conduct their operations in a context of free competition, which

takes place within a scheme of wholesale market, which consists of a market of contracts and a spot market. The contracts in the wholesale market can be signed between an energy consumer and an energy producer or between two energy producers.

In order to participate in the aforementioned markets, an IPP must first apply for a power generation license to the Ministry of Energy and Mines, except for power station with a capacity of less than 1 MW. Then, the IPP should ask for an authorization to the Nicaraguan National Dispatch Center to become an agent of the national electricity market. If the proposed power central uses public goods (e.g. if it is a hydropower or geothermal station) it also requires an authorization from the Ministry of Energy and Mines.

3.1.6. Panama

In Panama the market is open to private generators. Transmission and distributions are regulated by the government. There is only one transmission company, "*Empresa de Tranmisión Eléctrica*" (ETESA), which is owned by the state. It has a wholesale market formed by a contract market and a spot market. An IPP requires an authorization from ETESA to have access to the transmission system. This authorization is only given to IPPs that have already signed a PPA with an energy distributor. ETESA facilitates the sign of PPAs by periodically celebrating competitive bidding processes. IPPs with energy surplus not contracted must participate on all the bidding opportunities open by ETESA.

3.2. Regional electricity market

Motivated by the success of the pacification agreements obtained thanks to the coordinated effort of all the Central American countries, the region decided to initiate a multidimensional integration process which, among other things, considered the creation of a deregulated common electricity market. In 1996 the countries from Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama signed the Electricity Market Framework Treaty that eventually went into effect in 1998. This treaty explicitly expresses the interest of the signatories to start a gradual process of electrical integration through the development of a competitive Regional Electricity Market (REM), with dedicated transmission lines to interconnect their national networks and the promotion of regional generation projects.

The regional electricity market is operated and regulated by the following supranational institutions:

- "*Comisión Regional de Interconexión Eléctrica*" (CRIE) regulates the operation of the market.
- "*Ente Operador Regional*" (EOR) manages and coordinates the technical operation of Regional Power System and is in charge of the commercial management of the regional market.
- "*Empresa Propietaria de la Red*" (EPR) is responsible for the construction, operation and maintenance of the regional transmission system, which is called "*Sistema de Interconexión Eléctrica de los Países de América Central*" (SIEPAC). EPR is a company of private and public capital. Its shareholders are the local transmission companies, the Spanish energy company ENDESA, the Colombian energy company "*Grupo Empresarial ISA*" and the Federal Electricity Commission from Mexico.

The regional market allows us to sign short (spot market), medium and long term contracts among their participants. All the major actors of each local wholesale market can participate in the regional electricity market. Any actor from the regional market can freely access any national interconnected system. The tariff for the regional market should be approved by CRIE and the tariff from the national market is approved by the respective national regulatory agency.

SIEPAC, the transmission infrastructure of the regional market, has been explicitly built to allow power exchanges among participants in the REM. The construction started in 2006 and it was finally ended in 2013. SIEPAC consists of a 230 kV dedicated transmission line system installed across the six Central American countries. The longitude of these lines is of 1788 km and connects fifteen electrical substations spread in the region. This infrastructure represents a reliable and safe medium to transport 300 MW of electric power across Central America [3].

4. Central America electricity matrix: current situation

This section presents the current electricity generation profile of Central America. The region mainly produces electric energy from thermal and hydropower generators. Geothermal power generation has been timidly exploited since the 1970s. In the last decade, Costa Rica, Honduras and Nicaragua have ventured in wind power generation (see Figs. 5 and 6). Costa Rica and Nicaragua have recently finished the first two grid-connected photovoltaic central stations of the region.

Figs. 5 and 6 show the evolution of the electric energy capacity and generation, respectively, where thermal generation refers to power stations that use diesel, coal, sugarcane bagasse, gas and biogas. In 2012 71.4% of the thermal-based generated power used diesel as fuel [12]. A more detail discussion about the different fuels used for thermal generation is presented in Section 4.1.

Notice that according to Fig. 5 since the mid 1990s Central America has increased considerably their thermal power capacity. Nevertheless, thermal power stations, especially those based on diesel, are costly for the region and have produced negative effects in the past. For instance, as reported in [23], in 2009 some Central American countries have been forced to grant electricity tariff subsidies in order to cushion the effects of higher thermal generation costs as a result of the escalating oil prices. The behavior shown in Fig. 5 can be explained if we take into account the economical situation of the region in the mid 1990s and the differences between (1) the required initial investment and (2) the lead and construction times between thermal power stations and hydroelectric or geothermal power stations. Hydroelectric and geothermal power generation projects, besides having larger lead and construction times than thermal power stations, are often located in remote underdeveloped locations resulting in high transmission and development costs, and thus high, up front, capital investment cost, which recently privatized power companies are unlikely to accept [24]. This seems to be the case in Central America if we consider the largest private hydroelectric power station 94 MW built so far (finished in 2009) with the largest hydroelectric power plant of 300 MW [14] built by public companies.

On the other hand, Fig. 6 shows that hydroelectric power stations still generate the largest share of the total electric energy of the region (50% in 2012 according to [12]).

Moreover, there are important differences in the electric generation profile in each Central American country. These differences and some details about each electric energy source is discussed in the following.

4.1. Thermal power generation

In 2012, the total nominal capacity of thermal power generators connected to the grid was of 6125.8 MW, representing 49% of the total nominal power generation capacity. Notice, however, that

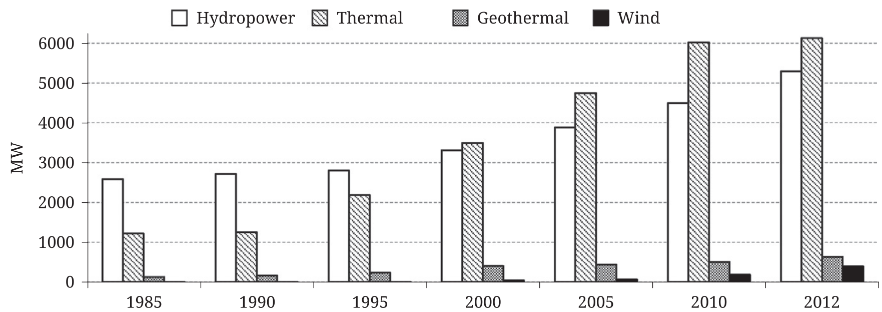


Fig. 5. Evolution of the installed power capacity in Central America.

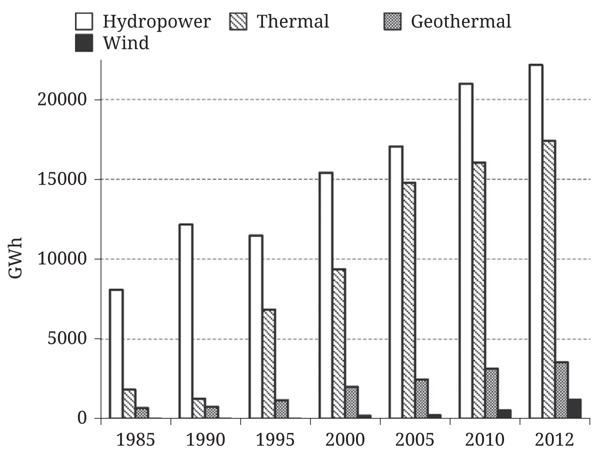


Fig. 6. Evolution of the amount of electricity generated in Central America.

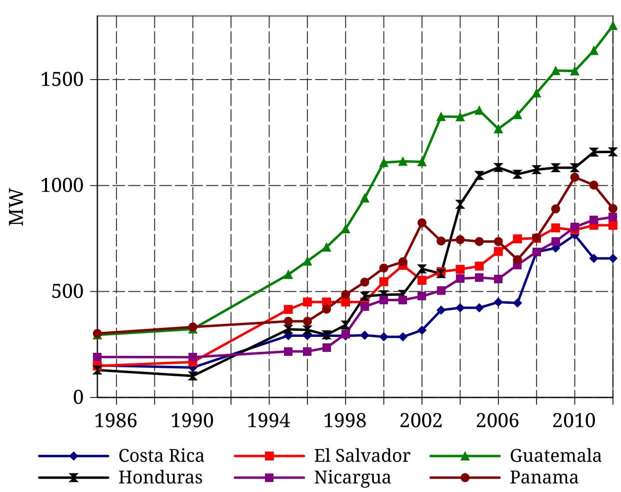


Fig. 7. Evolution of thermal power capacity in Central America.
Source: Economic Commission for Latin America [11,12].

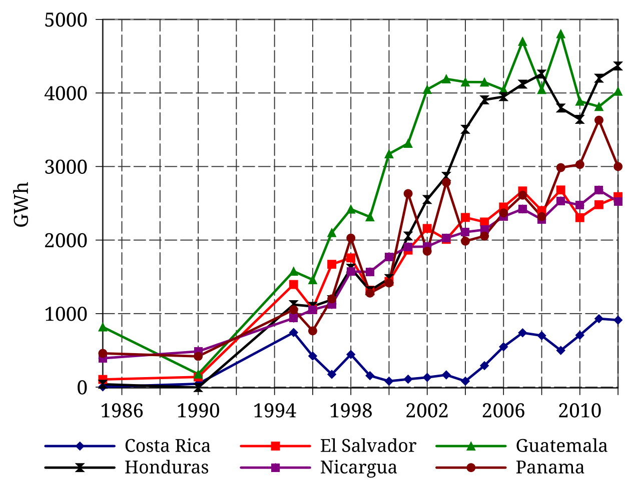


Fig. 8. Evolution of thermal power generation in Central America.
Source: Economic Commission for Latin America [11,12].

in that same year, thermal power generation represented 39.3% of the total energy generated in 2012 (approximately 17393 GW h) [12], which is due to the fact that Central American countries prefer to recur to their thermal power plants only when their other power plants (especially hydroelectric) cannot meet the demand. Fossil fueled thermal power generation is too expensive for a region in which oil is not abundant and has to be imported.

Figs. 7 and 8 show the evolution in the nominal capacity and generation of the thermal power plants in each Central American country. Recall that, as mentioned previously, the thermal power plants considered include those fueled mainly by diesel, coal, sugarcane bagasse, gas and biogas. In all the Central American diesel-fueled power stations provide by far the majority of the share of the thermal based power generation (71.4% of the total thermal-based generation). In 2012 Guatemala, Honduras and Panama were the only countries to report grid-connected coal based thermal power stations with a total capacity of 242 W, 37 W and 120 W, respectively. By 2012, in all the countries but Panama operated thermal power plants based on sugarcane bagasse, which represented 4.1% of the total power generation. In this same year, Costa Rica and El Savador produced electric energy from two small biogas-fueled power plants with a capacity of 3.70 W and 6.40 W, respectively.

As it can be seen in Fig. 8 Costa Rica is the only Central American country that has been able to keep the thermal power generation below 1000 GW h. As it is presented later in Section 4.2, the aforementioned is due to the fact that Costa Rica has been able to continue the development of its hydropower sector.

In total, Central America has 125 thermal power plants, the biggest fossil fuel based power plant has a capacity of 280 MW and is located in Panama. The biggest thermal power plant based on sugarcane bagasse with a capacity of 131 MW is located in Guatemala.

4.1.1. *Fossil-fuel based thermal power generation*

Central America lacks abundant oil reserves. The only significant proven oil reserves are those located in the Yucatan Block, a microplate of about 450 000 km^2 shared by Mexico, Guatemala and Belize [25].

The biggest Central American oil field, the Xan Field, is located in the aforementioned block, more specifically, in the northwestern

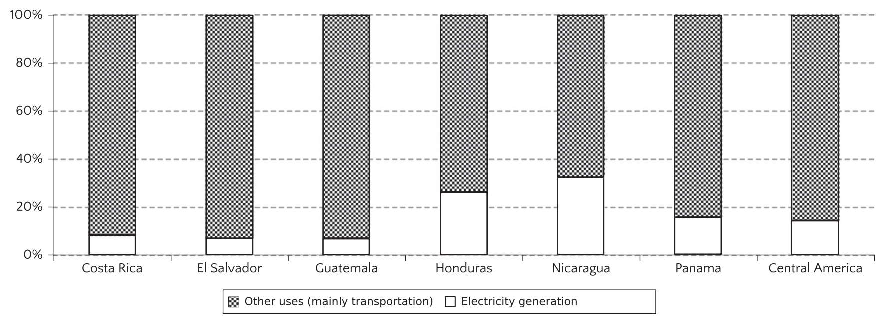


Fig. 9. Distribution of oil consumption by the different sectors in 2010.
Source: Economic Commission for Latin America [26].

part of the Peten Department of Guatemala. The oil reserve of the Xan field is estimated to be around 100 million barrels.

In 2011 Guatemala produced about 11 000 barrels of oil per day, which represented only 0.15% of the crude oil produced in Latin America and 0.013% of that produced in the World. In 2010, the region imported 9321 millions of USD, representing 16.1% of the total value of the net exports on the same year. Nevertheless, it should be pointed out that the petroleum use for electricity generation represents only a small percentage of the total consumed petroleum derivatives, as it can be verified in Fig. 9.

4.1.2. Biomass based thermal power plants

Biomass based thermal power plants were responsible of producing about 1816.2 GW h of electricity in 2012 [12]. All of the aforementioned amount of electricity which represents a 4% of the total power generated in 2012 has been produced in sugarcane mills, using sugarcane bagasse as fuel. The sugarcane industry in Central America is a well organized sector that has a great autonomy for steam and electricity production [6].

Central America is a major sugarcane producer. According to World Bank statistics [13], in 2011 Central America produced almost 46 millions of tonnes of sugarcane. The region ranks as the 8th sugarcane producer in the world.

4.2. Hydroelectric generation

Central America has many mountain ranges with high peak mountains such as the Tajamulco volcano (elevation: 4220 m) located in north of the isthmus or the Chirripó mountain (elevation: 3820 m) located in the South. These ranges, which go all along the narrow strip of the isthmus, and the high precipitation conditions of the Tropical climate make the region very rich in terms of water resources. Costa Rica, having more than 90% of their total generated electricity coming from hydroelectric power plants, is a good example of that. In 2012, Central America made use of their 150 hydroelectric power plants to generate 50% of the total electric energy [27].

Figs. 10 and 11 depict the evolution of hydropower station's capacity and generation for each Central American country. Notice that Costa Rica has been the only country that has been able to keep a sustainable growth in the hydropower generation and capacity which might be due to its relatively better economic situation than the other Central American countries and having a strong public utility company, ICE, which monopolizes the electricity market. Nevertheless, in recent years, Panama and Guatemala have been able to successfully attract private investors for hydropower projects.

The major hydroelectric power plants in the region are located in Honduras, Panama and Guatemala and all of them have a nominal capacity of 300 W. In 2012, Costa Rica was the country with the larger number of operating hydroelectric power plants, 46, followed by Guatemala (41), Panama (31), Honduras (24), El Salvador (8) and Nicaragua (3).

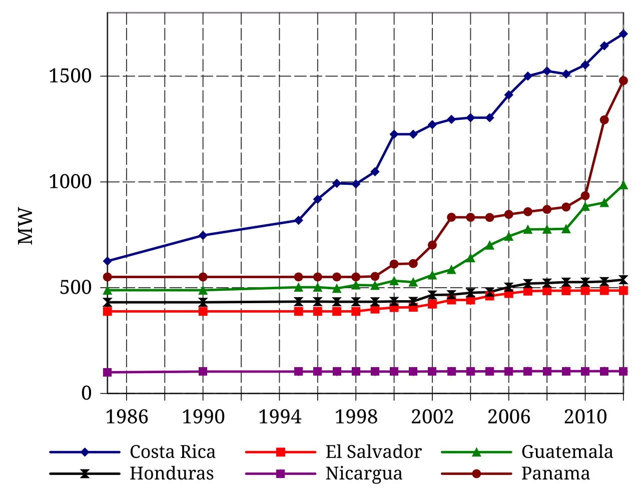


Fig. 10. Evolution of hydropower capacity in Central America.
Source: Economic Commission for Latin America [11,12].

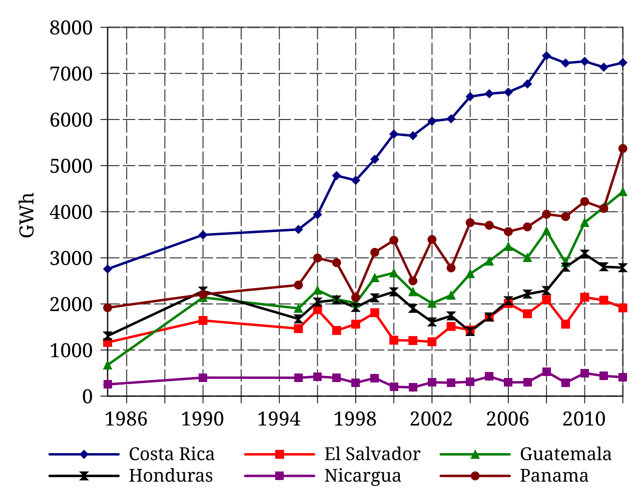


Fig. 11. Evolution of hydropower generation in Central America.
Source: Economic Commission for Latin America [11,12].

4.3. Geothermal generation

Central America has been exploiting its geothermal resources for electricity generation since the 1970s. El Salvador has been the first Central American country to put on line a commercial geothermal power plant [28], followed by Nicaragua and Costa Rica (Figs. 12 and 13).

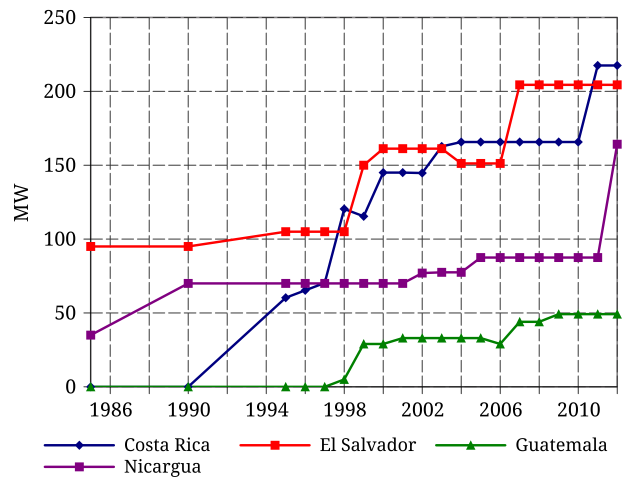


Fig. 12. Evolution of geothermal power capacity in Central America.
Source: Economic Commission for Latin America [11,14].

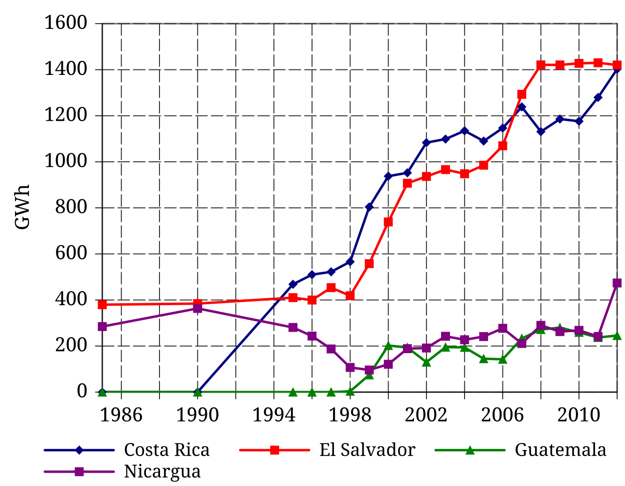


Fig. 13. Evolution of geothermal power generation in Central America.
Source: Economic Commission for Latin America [11,14].

The majority of the geothermal potential is concentrated along the Central American's Pacific Rim, a tectonic active volcanic region. Due to its geographic position, Honduras and Panama are the countries with less geothermal potential, whereas Nicaragua is the country with the highest geothermal potential [28].

The biggest geothermal project is Miravalles, located in Costa Rica and runned by the Costa Rican electricity company ICE and a private consortia. The geothermal units of Miravalles complex have a total nominal capacity of 217.46 MW [12]. Honduras and Panama do not have at the moment any geothermal plant.

4.4. Wind generation

The first wind turbines connected to the utility grid in Central America were installed in Costa Rica in 1996. This wind farm, still in operation, has a maximum capacity of 20 MW.

In recent years there has been a lot of interest in wind energy in the region, mainly from the private sector. In 2011 11 different wind farms with a total maximum capacity of 395.8 MW generated 1190 GW h [27]. That year, only three countries, Costa Rica, Honduras and Nicaragua, injected wind energy to the power grid. The contribution of each country to the electricity generated and the power capacity is graphically shown in Figs. 15 and 14, respectively. The biggest wind farm in Central America has a capacity of 102 MW and is located in Honduras.

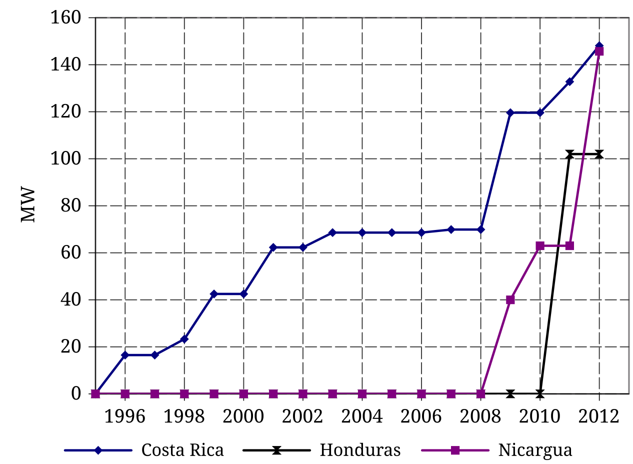


Fig. 14. Evolution of wind power generator's capacity in Central America.
Source: Economic Commission for Latin America [11,27].

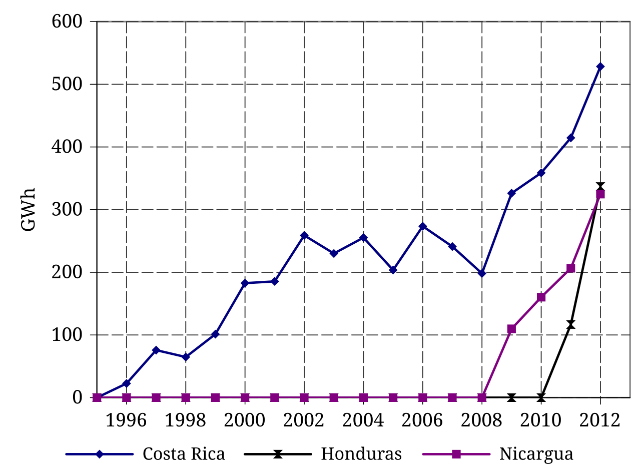


Fig. 15. Evolution of wind power generation in Central America.
Source: Economic Commission for Latin America [11,27].

4.5. Solar energy

Until 2012 there were no solar-based power plants connected to the grid in Central America. In Costa Rica, the public power company ICE has finished a 1 MW solar plant that has been connected to the grid at the end of 2012. This solar power plant has been almost entirely financially supported by the Japanese government [29,27].

The Japanese government has also partially financially supported a 1.38 MW solar plant in Nicaragua that has started to deliver energy to grid in 2013 [30].

5. Analysis and trends of the Central America electricity sector

This section briefly analyzes the trends in the Central American electricity subsector emphasizing the potential role of renewable energy power generation. The discussion in this section is based on the current policies and expansion plans and the role of the regional electricity market.

5.1. Power expansion plans and largest power plants under construction

The power expansion plans of the six Central American countries are summarized in the report "Indicative Plan for Regional Generation Expansion" [31] elaborated by the Working

Table 2
Largest renewable energy projects under construction in Central America.

Name	Type	Expected capacity (MW)	Country	Notes
Diquís	Hydropower	631	Costa Rica	Negotiating with the indigenous people of the zone, there have been concerns about the environmental impact, expected to start to operate in 2020
Reventazón	Hydropower	306	Costa Rica	Construction started in 2012, expected to enter in operation in 2016
Tumarín	Hydropower	253	Nicaragua	Constructions will start in October 2013 [33]
Patuca III	Hydropower	104	Honduras	It has been facing financial problems but the second phase of the project (dam construction and installation of equipment and machinery) has started in 2013 [34]. It is expected to start to operate in 2014
Renace II	Hydropower	114	Guatemala	Developed by the private Guatemalan company "*Corporacion Multi Inversiones*" and currently under construction. It is expected to start to inject energy to grid in 2014 [35]
Penonomé	Wind	220	Panama	It will be the biggest wind farm in Central America which will start to operate in 2014 [36]

Group on Regional Planning (GTPR) of the Central American Electrification Council. According to the aforementioned source, by 2014 the power generation capacity in Central America will be increased mainly due to new projects in hydropower, wind energy and natural gas. Most of the increased power capacity in the short term will be due to upgrades on the currently available power stations (e.g. Moin thermal power plant in Costa Rica going from 130 MW to 210 MW [32]) or on the development of small hydro, geothermal and sugarcane bagasse-fired power plants. The biggest new project expected by 2014 is a natural gas-fired power plant in Honduras of 100 MW to enter in operation in 2013. It should also be highlighted two new wind energy projects in Nicaragua of 37 MW and 40 MW that will start to inject energy to the grid in 2013 and 2014, respectively, and the 14 MW grid-connected photovoltaic plant to be finished in El Salvador in 2014.

In the long term (2014–2026) almost all the Central American countries plan to install mid range power capacity renewable energy projects as it is summarized in Table 2. Relatively large (> 100 MW) hydropower projects have been having difficulties mainly due to the lack of up-front capital to start the project or due to their associated environmental and social negative impacts. For instance, consider the case of the Honduran hydropower project of "*Jicatuyo y Los Llanitos*" that can potentially add 210 MW to the Honduran power capacity. The public utility company ENEE does not have enough resources to start this project on its own and has also been unable to find private partners interested in co-developing the project [37]. Almost all the largest hydropower projects on the region, i.e., Diquis (Costa Rica), Reventazon (Costa Rica) and Patuca III (Honduras), have caused conflicts with the surrounding population or with environmentalists [38–40].

Regarding geothermal energy, Nicaragua expects to construct about 10 geothermal power plants by 2026 with an average capacity of 30 MW each [31]. The Costa Rican government and the Costa Rican public power company, ICE, are also very interested in exploiting the geothermal energy available in the country. Nevertheless, the majority of the sites which are most suitable for geothermal exploitation are located in protected natural reserves or natural parks. A law that will allow us to construct geothermal power plants in natural parks is currently under discussion [41].

Even though the efforts done by the region to diversify its electricity mix, fossil fuel thermal power plants will still have a significant role in the Central American electricity mix. According to [31], after 2020 some countries will need to put into operation fossil fueled thermal power plants in order to meet their energy demands. Moreover, it is expected a major shift from oil-fired towards gas-fired power plants, mainly due to the less variability of natural gas prices with respect to oil prices. Indeed, the strategic energy plans of almost all the Central American countries [32,42–44] explicitly state the interest not only on switching to gas-fired power plants but also on creating natural gas storage terminals. In the case of Guatemala, the Ministry of Energy and Mines have decided to intensify the natural gas exploration in its territory [43]. Even though, there are currently no large power capacity (> 300 MW) gas-fired power plants under construction, at least Guatemala, Honduras, El Salvador and Panama expect to attract private investment to construct 500 MW gas-fired thermal power plants by 2020 [31]. Additionally, there have been studies that suggest the possibility of building a natural gas pipeline from Mexico and Colombia making the access to natural gas more reliable and cheaper for the region [45].

Coal fire-power plants is another alternative to diesel-based power plants that some Central Americans are considering. Even though, all the coal used in the region is imported [45], its price is lower and less volatile than oil derivatives. Guatemala is currently constructing a 300 MW coal-fired power plant that will start to operate in 2015 [46]. ENEE, the Honduran utility company is planning on starting a bidding process to build a 300 MW carbon-fired thermal plant [47].

5.2. Regional market

Another factor that will possibly modify the power generation profile of Central America is the regional electricity market (REM) (see Section 3.2). The regional market with its dedicated interconnection infrastructure started to operate in 2013. In the 2012 report of the Working Group on Regional Planning (GTPR) of the Central American Electrification Council, [31], it has been foreseen at least a 50% increase in the international energy transactions between the Central American Countries between 2011 and 2026. According to the aforementioned report, Honduras and El Salvador will become electric energy importers, making the consolidation of the regional market essential for their energy security.

It is also important to highlight that the Central American electric system will also interact with two majors actors, namely, Colombia and Mexico. Currently there exists an interconnection between Guatemala and Mexico, and the Colombian and Panamanian governments have been discussing the implementation of a bi-national energy agreement that will allow the two countries to exchange up to 300 MW [48]. It is expected that by 2015 there will be a 300 MW capacity interconnection between Colombia and Panama [49]. Also, by 2020, the SIEPAC capacity will be increased to 600 MW, including the Panama–Colombia connection. Thus, in practical terms, Colombia and Mexico will be part of the Central American Electrical Interconnection System. The Guatemalan government have stated as an explicit action on its strategic energy plan to profit the Mexican low electric energy prices [43]. Other Central American countries also intend to benefit from the access of cheaper electrical energy from Mexico and Colombia [31]. Moreover, the strategic energy plan from several Central American countries [32,42–44] has as one of its primary objectives the active participation in the REM. It is also expected that the REM will allow attracting private companies to invest in larger power projects. In this respect, there has been a previous

experience: in 2010 a Honduran group of private investors inaugurated the Xacbal (94 MW capacity) hydroelectric power station in Guatemala to sell part of its electrical energy to El Salvador [14]. It is expected that similar schemes become more frequent as REM develops.

5.3. Conclusions

The Central American Region have been able to maintain a clean electric energy production in recent years. The lack of locally abundant oil and coal reserves, the increase in oil prices and, in some minor degree, the role of international cooperation agencies and development banks have helped the implementation of small non-traditional renewable energy projects. However, the experienced economic growth and its recently active participation in the global economy pushes the region to look for cheaper power that requires short lead and construction times. The aforementioned and the lack of capital of local public and private companies to start large renewable energy projects have favored the construction of fossil fuel based power stations, mainly oil-fired ones.

To a greater or lesser degree, all the Central American countries rely on the regional interconnected electric system to have access to cheaper and reliable electricity. On one hand larger power projects can become viable in the framework of the regional electricity market and, on the other hand, connecting the region to Colombia and Mexico may allow them to have access to cheaper electricity.

The region's main objective in the power sector is to reduce medium and longer-term vulnerability to high volatile oil prices. Being aware of the difficulties related to the development of large hydropower projects, i.e., lack of capital and negative socio-environmental impacts, Central American countries are starting to consider the utilization of gas-fired or coal-fired power plants. In any case, the development of large power stations will be subject to the development of the regional market.

Finally, the latest reforms on the legal framework of the Central American countries manifest their willingness to develop the power sector with the private industry.

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